ENGINEERING SERVICES FOR THE NEXT GENERATION NUCLEAR PLANT (NGNP) WITH HYDROGEN PRODUCTION

Test Plan - Shutdown Cooling Heat Exchanger

Prepared by General Atomics For the Battelle Energy Alliance, LLC

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GA Project 30302

















GA 1485 (REV. 08/06E)

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ACRONYMS

| ASME | American Society of Mechanical Engineers |
|----------|---|
| ASTM | American Society of Testing and Materials |
| CCD | Conduction Cool Down (event) |
| CTF | Component Test Facility |
| DDN | Design Data Need |
| DOE | U.S. Department of Energy |
| FSV | Fort Saint Vrain |
| GA | General Atomics |
| GT-MHR | Gas Turbine Modular Helium Reactor |
| HTGR | High-Temperature, Gas-Cooled Reactor |
| HTTR | High Temperature Test Reactor |
| INL | Idaho National Laboratory |
| NGNP | Next Generation Nuclear Plant |
| MHR | Modular Helium Reactor |
| MHTGR | Modular HTGR |
| NP-MHTGR | New Production Modular HTGR |
| ORNL | Oak Ridge National Laboratory |
| SCHE | Shutdown Cooling Heat Exchanger |
| TRL | Technology Readiness Level |

1 INTRODUCTION

1.1 Purpose

This Test Plan provides a high-level description of a test program to support design, fabrication, and deployment of the shutdown cooling heat exchanger (SCHE) for the Next Generation Nuclear Plant (NGNP). Startup of the NGNP is currently scheduled for 2021. The described activities are those that are seen at this time as necessary to advance the Technology Readiness Level (TRL) of the SCHE from its current level (assigned by GA as TRL 4) to the level (TRL 8) required prior to hot startup of the NGNP.

This Test Plan is applicable to an SCHE for the plant configuration shown in Figure 1, which General Atomics (GA) selected as its preferred configuration for the NGNP during the FY08-1 Conceptual Design Studies in early 2008 (GA Report 911120). This plant configuration is consistent with the high-level requirements for the NGNP that existed at that time, and it was selected at the onset of the NGNP technology development roadmapping task under which this Test Plan has been prepared as the basis for the technology development roadmapping effort.¹

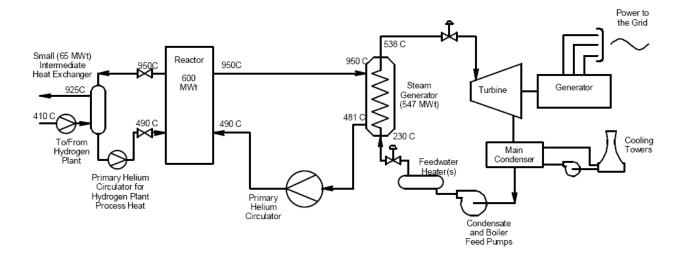


Figure 1. NGNP Configuration for Technology Development Roadmapping

Because the NGNP design process is at a very early stage, adequate design details to precisely define testing requirements are not currently available. Consequently, this Test Plan is intended

¹ A decision has been made by the NGNP Project to reduce the nominal reactor outlet helium temperature for the NGNP from 950°C into the range of 750°C to 800°C with a corresponding reduction in the reactor inlet helium temperature. However, the technology roadmapping task was started and largely completed while the reactor outlet helium temperature objective for NGNP was still 950°C. Thus, the focus has been to define the technology development activities required for a reactor operating at that temperature.

primarily to identify the design and testing activities that are likely to be needed and to provide cost and schedule estimates, which are based primarily on engineering judgment at this point in time. It is assumed that this Test Plan will be updated periodically as the NGNP design progresses and that detailed test plans and test procedures will be prepared by the testing organizations for the specific tests that actually need to be conducted.

1.2 Scope

The scope of this SCHE Test Plan is to outline all of the activities required to advance the TRL of the SCHE from 4 to 8. The first TRL step will be accomplished via computer modeling. The modeling will be performed to establish the following:

- The required heat exchanger size including the number and size of the tubes, the overall diameter of the SCHE and the length of the SCHE flow paths
- The heat exchanger flow resistance
- The temperature and pressure levels within the SCHE and on all of the structural components
- The structural characteristics of the tubes
- The structural characteristics of the tube support method
- The structural characteristics of the shroud and its insulation system

Selection of the shroud material, insulation material, and material(s) for the insulation cover plates and attachments will be made based on the results of these analyses.

The following testing is judged necessary to support the SCHE design effort and to verify the final SCHE design.

- 1. Testing of the shroud and its insulation to show compatibility with design conditions and to show that the shroud is leak tight (DDNs C.14.04.01 and C14.04.05)
- 2. Testing of the response of the tubing to acoustic noise (DDN C.14.04.06)
- 3. Testing to establish the shell side temperature and flow distribution at the heat exchanger inlet. If flow distribution devices are determined to be needed, then testing of candidate designs will also be performed (DDN C.14.04.07)
- 4. Testing of the tube support system and the tube wear protection devices to assure that the tube support system will not cause tube wear as the result of vibration, fretting and sliding (DDN C.14.04.02)
- 5. Testing of the fabrication method for helical coiled tube (DDN C.14.04.09)
- 6. Testing of the method for attaching instrumentation (DDN C.14.04.03)
- 7. Airflow testing of a full-size SCHE to verify the heat transfer and vibration characteristics of the tube bundle (DDN C.14.04.08)

8. Testing of a full-size SCHE in a helium environment under all possible operating conditions to assure the SCHE will meet performance requirements

Tests 1 through 3 will advance the TRL of the SCHE from 5 to 6. Tests 4 through 6 are common to the steam generator and SCHE helical coil designs and will be performed as elements of the steam generator design support test program. These tests must also be successfully completed to advance the TRL of the SCHE from 5 to 6. Tests 7 and 8 must be successfully completed to advance the TRL of the SCHE from 6 to 7 and from 7 to 8, respectively. Tests 1, 2, 3, 7, and 8 are discussed in this Test Plan. Tests 4 through 6 are covered in the Test Plan for the steam generator (GA document 911142) and are therefore not included herein.

A summary of the estimated costs and an overall schedule for SCHE technology development are given in Section 2 in Table 2 and Figure 3, respectively.

1.3 Background

The primary function of the SCHE is to provide reactor cooling when the Primary Cooling System (PCS) is not available for operation.

The SCHE is a water-cooled, multi-tube helical-coil heat exchanger (Figure 2). The tubes are supported by support plates and are enclosed in a shroud that directs the reactor coolant (normally helium, but during a depressurized event the coolant can be a mixture of helium and air) across the heat exchanger tubes. The SCHE design is similar to the design of the Fort Saint Vrain (FSV) steam generator.

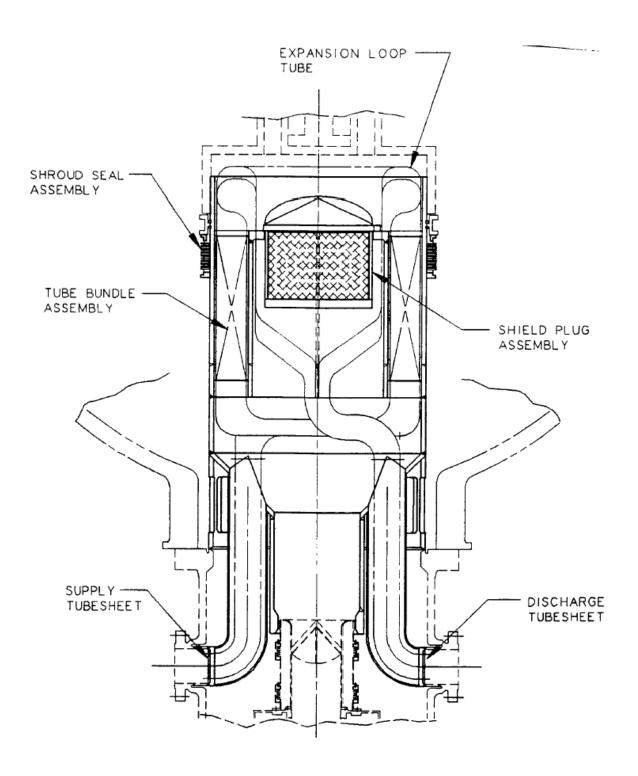


Figure 2. Shutdown Cooling Heat Exchanger

2 APPLICABLE DOCUMENTS

Table 1. Documents Applicable to SCHE Design

| Document Number | Title |
|----------------------------|--|
| ASME 74-WA/HT-7 | Core Auxiliary Heat Exchanger for a High-Temperature Gas Cooled Reactor: Water Side Static Stability Analysis and Design |
| ASME 83-JPGC-NE-15 | Comparison of Calculated Results from Two Analytical Models with Measured Data from Heat Exchanger Flow Test |
| GA-A16214 | Experimental and Analytical Investigation of Shell-side Flow Distribution Effects on Axial Flow Heat Exchangers |
| GA document 911120, Rev. 0 | NGNP Steam Generator Alternatives Study, April 2008 |
| PC-000396, Rev. 1 | PC-MHR Engineering Development Plan, November 1995 |
| DOE-GT-MHR-100217 (Draft) | 600 MW(t) Gas Turbine – Modular Helium Reactor Design Data Needs, July 1994 |
| CEGA-002712 | Engineering Development Plan for the New-Production Modular High- Temperature Gas-Cooled Reactor Program |
| GA document 911142, Rev. 0 | Test Plan – Steam Generator, Helical Coil Design |

3 TRL 4 TO 5 – DESIGN AND ANALYSIS

Based on the previous experience with the FSV helical coil heat exchanger, which is similar in design to the SCHE, the initial TRL level for the SCHE is set at 4. The progression from TRL 4 to TRL 5 is achieved via the SCHE design effort. This effort includes computer analysis to evaluate the heat exchanger thermal/hydraulic and structural performance for all possible operating conditions. The operating conditions include pressurized cooldown from 100% power (sets the sizing requirements), depressurized cooldown from 100% power (establishes the pressure drop requirements), steady state operation at full power and conduction cooldown. The analysis will also provide data for making shroud and shroud insulation material selections.

This effort will cost \$2.0M. This effort will start at the beginning of conceptual design and take about two years to complete.

4 TESTING TO ADVANCE FROM TRL 5 TO 6

The four tests described in this section are required to advance the TRL from 5 to 6. Three of these tests will be performed on a mockup of the heat exchanger bundle, the heat exchanger shroud and the region between the core outlet and the heat exchanger inlet. These tests will support DDNs C.14.04.01, C.14.04.05, C.14.04.06, and C.14.04.07. The fourth test (tube flow stability orifice test) can be run on a section of SCHE tubing.

As noted in Section 1.2, a number of tests that are also required to advance the TRL of the SCHE from 5 to 6 are common to the steam generator and SCHE helical coil designs and will be performed as elements of the steam generator design support test program. These tests are covered in the Test Plan for the steam generator (GA document 911142) and are therefore not included herein.

4.1 Shroud Seal Test

4.1.1 Test Objectives

The SCHE shroud seal is critical to the performance of the SCHE. If the seal leaks a portion of the primary coolant will bypass the heat exchanger. Thus, the primary function of the heat exchanger will be compromised. This test will identify possible leak modes and can also be used to define design changes needed to eliminate /reduce the leaks.

4.1.2 Test Description

Perform testing of the SCHE shroud seal to determine measured leakage rates for combinations of different surface finishes, flatness tolerances, loads, and differential pressures under typical operating conditions. The shroud seal design consists of a metal bellows spring that compresses a circumferential seal. The testing will also include mechanical testing of the bellow assembly.

4.1.3 Test Conditions

Service Temperatures

100 % Plant Power He Side 490°C Maximum

Shutdown Cooling He Side TBD as a function of plant design Plant Transients He Side TBD as a function of plant design

Service Pressures

Helium Side 7.0 MPa maximum

4.1.4 Test Configuration

Testing will be performed on a mockup of the heat exchanger bundle, the heat exchanger shroud and the region between the core outlet and the heat exchanger inlet.

4.1.5 Measurements

There are two types of measurements required for this test: measurements of environmental conditions and measurements that would indicate leak rates. The measured parameters include:

- Temperature
- Pressure
- Flow Rates
- Seal Loads

4.1.6 Test Duration

As noted above, this test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The total duration is estimated to be about 2 years.

4.1.7 Proposed Test Location

There are several possible test facilities, including:

1. Argonne National Laboratory, Nuclear Engineering Division

9700 South Cass Ave., Argonne, IL 60439-4

Director:

Hussein S. Khalil

Fax (630) 252-4780

Email neinfo@anl.gov

http://www.ne.anl.gov/activ/cap mt.html

Capabilities within the Materials Testing division include:

- Environmentally Assisted Cracking (EAC) of Reactor Materials
- Corrosion Performance/Metal Dusting
- Irradiated Materials
- Heat Exchanger Tube Integrity

The Flow-Induced Vibration Test Facility (FIVTF) at Argonne National Laboratory (ANL), Components Technology Division, had water-flow facilities including pump capacities of 500, 1000, 2500, and 4000 gpm. For the air flow tests outlined here, it recommended to contact ANL to inquire about what air flow test facilities may exist at ANL. As with other national

laboratory and private industry test facilities, the capabilities may be been reduced or eliminated during the last decade or two.

2. National Technical Systems

24007 Ventura Blvd #200 Calabasas, CA 91302 (800) 270-2516

http://www.ntscorp.com/

NTS provides integrated engineering services and technical solutions, product testing and design for compliance, regulatory standards compliance testing and evaluation, project management, technical resources, engineering solutions and managed services. NTS is globally accredited by many leading regulatory agencies. NTS has testing laboratories and engineering services offices located in North America, Europe and Asia. NTS is the largest independent testing laboratory in the world.

4.1.8 Data Requirements

Quality Assurance must be in accordance with the requirements for experimental data or validation testing.

4.1.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of Test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

4.1.10 Costs, Schedule and Risk

4.1.10.1 Cost

\$ 350,000

4.1.10.2 Schedule

This test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The total duration is estimated to be about 2 years starting at the beginning of preliminary design.

4.1.10.3 Risk

The heat exchanger shroud is critical to the heat exchanger performance. If the shroud should leak the heat exchanger performance will be less than required. Testing is required to assure that it does not leak.

4.2 Inlet Flow and Temperature Distribution Tests

4.2.1 Test Objectives

Documented analysis and testing of various heat exchanger configurations have shown that shell side inlet flow and/or temperature maldistribution can cause major performance degradation. Tests on the shell-side inlet flow configuration will establish if a inlet flow distribution device is required at the heat exchanger inlet to eliminate flow and/or temperature maldistributions. This effort should be coordinated with CFD analysis of the inlet region.

4.2.2 Test Description

The inlet flow/temperature distribution test will require a mockup of the reactor core outlet region and the heat exchanger inlet region. Airflow tests will be required to establish the flow distribution into the heat exchanger. If analysis of the inlet distribution shows that the flow maldistribution is not acceptable, then an inlet flow distribution device must be designed and tested to establish an acceptable flow distribution into the heat exchanger.

In order to establish the effect of hot streaks, airflow testing using local heat sources at the mockup of the core exit will be required. The temperature distribution must be measured at the heat exchanger inlet. Using analytical tools, the effect of the hot streaks on the heat exchanger performance can be determined. If the effect is not acceptable, then a mixing device must be designed and tested for installation at the heat exchanger inlet.

In addition to establishing the inlet flow and temperature distribution this test will provide data to establish the frequency response and dynamic loads on the shroud insulation cover sheets.

4.2.3 Test Conditions

The test conditions must simulate the design flow distributions and temperature distribution as established by detailed reactor core analysis.

4.2.4 Test Configuration

This test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The test configuration is described in Section 4.1.4.

4.2.5 Measurements

The following measurements are required.

- Flow Rate
- Velocity Distribution into the heat exchanger mockup.
- Temperature distribution into the heat exchanger mockup.
- Pressure level and pressure drop
- Insulation cover sheet frequency response and dynamic loads

4.2.6 Test Duration

This test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The total duration is estimated to be about 2 years.

4.2.7 Proposed Test Location

Same as Section 4.1.7

4.2.8 Data Requirements

Quality Assurance must be in accordance with the requirements for experimental data or validation testing.

4.2.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of Test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

4.2.10 Costs, Schedule and Risk

4.2.10.1 Cost

\$ 1.25M

4.2.10.2 Schedule

This test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The total duration is estimated to be about 2 years starting at the beginning of preliminary design.

4.2.10.3 Risk

Based on previous testing and calculations (see documents ASME 83-JPGC-NE-15 and GA-A16214), it is likely that a poor flow distribution and/or temperature distribution at the heat exchanger inlet will result in not achieving the desired heat exchanger performance. However, if testing is not performed, then detailed CFD analysis must be performed. If the distributions are such that the heat exchanger performance is not satisfactory, then flow/temperature distribution devices must be designed. These devices should be tested to assure their adequacy.

4.3 Acoustic Noise Test

4.3.1 Test Objective

Perform tests to investigate the effects of acoustic noise on the large surface area structures of the SCHE.

4.3.2 Test Description

These tests will include the effects of coolant flow through the tube bundle so that the combined effects of acoustic noise and flow induced vibration can be assessed.

4.3.3 Test Conditions

Same as Section 4.2.3

4.3.4 Test Configuration

Same as Section 4.2.4

4.3.5 Measurements

Same as Section 4.2.5

4.3.6 Test Duration

This test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The total duration is estimated to be about 2 years.

4.3.7 Test Location

Same as Section 4.1.7

4.3.8 Data Requirements

Quality Assurance must be in accordance with the requirements for experimental data or validation testing.

4.3.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of Test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results observations and calculations that were completed throughout the course of testing

4.3.10 Costs, Schedule and Risk

4.3.10.1 Costs

\$ 450,000

4.3.10.2 Schedule

This test will be run simultaneously with the other tests required to advance the TRL from 5 to 6. The total duration is estimated to be about 2 years starting at the beginning of preliminary design.

4.3.10.3 Risks

Acoustic noise can cause damage to either the shroud or the insulation cover sheets.

4.4 Inlet Orifice Flow Testing

4.4.1 Test Objective

As described in document ASME 74-WA/HT-7, tube inlet orifices are required to assure flow stability. These orifices can be sized via computational methods, but their pressure drop characteristics must be verified by test.

4.4.2 Test Description

A length of SCHE tubing with a stability orifice installed will be flow tested to establish the pressure drop loss coefficient for the orifice.

4.4.3 Test Conditions

The test will be performed using water at 60°C.

4.4.4 Test Configuration

The test configuration would consist of a length of SCHE tubing with a stability orifice installed. The test would require a source of water at 60°C.

4.4.5 Measurements

The following measurements must be made.

- Water flow rate
- Water temperature
- Water pressure
- Pressure drop across the orifice

4.4.6 Test Duration

Test duration is about 2 months.

4.4.7 Proposed Test Location

This test could be performed at the General Atomics Test Tower or at any of a number of other test facilities including those identified in Section 4.1.7.

3550 General Atomics Court San Diego, CA 92121-1122 (858) 455-3000

4.4.8 Data Requirements

Quality Assurance must be in accordance with the requirements for experimental data or validation testing.

4.4.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of Test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results observations and calculations that were completed throughout the course of testing.

4.4.10 Costs, Schedule and Risks

4.4.10.1 Cost

\$100,000

4.4.10.2 Schedule

The total duration is estimated to be about two months and the test would be performed sometime within the same time period as the tests in Section 4.1, 4.2, and 4.3.

4.4.10.3 Risk

As described in document ASME 74-WA/HT-7, inlet orifices are required to assure flow stability. If the orifice does not meet the pressure drop requirements as established by analysis it is possible for an unstable flow condition to exists. Flow instability can lead to tube dry-out and tube failure.

5 TRL 6 TO 7 - AIRFLOW TESTING OF A FULL-SCALE SCHE

This test is required to move from TRL 6 to 7.

5.1 Test Objectives

This test will verify the heat transfer and vibration characteristics of a full size SCHE.

5.2 Test Description

A full size SCHE will be built and tested in air. This test will establish the SCHE thermal and vibration performance for conditions that are similar to the design conditions.

5.3 Test Conditions

The test conditions should simulate the design conditions as closely as possible. For the thermal tests the airflow rate should be selected so as to match the same Reynolds Number range (laminar vs. turbulent) as would be present in the design case. The air should be heated to (TBD). The heat exchanger cooling water flow, inlet temperature and pressure should match the design values. For the vibration tests the airflow conditions should match as closely as possible the design conditions that would result in the maximum vibration loads.

5.4 Test Configuration

The test configuration would consist of the following components.

- A full size SCHE
- Large fans
- Air Heaters
- Water cooler (heat exchanger)
- Water pump
- Water treatment system
- Instrumentation and the necessary equipment (computers etc.) to provide the required control data and to save and/or process all of the critical performance data

5.5 Measurements

The following measurements are required for the airflow test:

- Air flow rate
- Air inlet temperature
- Air exit temperature
- Air inlet pressure

- Air exit pressure
- Air inlet velocity
- Air exit velocity
- Water flow rate
- Water inlet temperature
- Water exit temperature
- Water inlet pressure
- Water exit pressure
- Tube wall temperatures
- Tube wall strain
- Tube displacement measurements

5.6 Test Duration

Six months for fabrication of test rig plus six months for testing and data reduction.

5.7 Proposed Test Location

The General Atomics Test Tower is a potential location for the test. A FSV steam generator module was airflow tested at the General Atomics Test Tower (see documents ASME 83-JPGC-NE-15 and GA-A16214).

3550 General Atomics Court San Diego, CA 92121-1122 (858) 455-3000

An alternative location would be the INL Component Test Facility.

5.8 Data Requirements

Quality Assurance must be in accordance with the requirements for experimental data or validation testing.

5.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of Test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data

- Summarized and reduced test data
- A detailed discussion of test results observations and calculations that were completed throughout the course of testing.

5.10 Costs, Schedule and Risks

5.10.1 Cost

\$5.0M. This cost does not include the fabrication of the full-size SCHE prototype. The cost of SCHE prototype fabrication is estimated to be about \$6.0M in 2008 dollars.

5.10.2 Schedule

Fabrication of the test rig should start about one year into final design.

5.10.3 Risk

This test provides the last opportunity to determine the need for any modifications to the SCHE prior to testing in helium. If this test is not performed, any needed corrections uncovered during the full-scale helium testing could require major rework resulting in am NGNP schedule delay.

6 TRL 7 TO 8 - FULL SCALE SCHE TESTING IN HELIUM

This test is required to move from TRL 7 to 8.

6.1 Test Objective

This test will consist of a series of standby and operational tests that will duplicate all possible operating conditions including standby operation when the plant is operating at various power levels, pressurized shutdown and depressurized shutdown. The standby tests will show that the SCHE will not be harmed by normal plant operation and this test will also establish the parasitic heat loss during normal plant operation, The shutdown tests will establish the ability of the heat exchanger to perform both in pressurized helium and in a depressurized mixture of helium and air. The shutdown tests will also establish the heat exchangers ability to perform without damage during a transient operating condition.

6.2 Test Description

The SCHE is subjected to various operating conditions, which include standby operation during normal plant operation, pressurized shutdown in a 100% helium environment and depressurized shutdown in a helium/air mixture. Since each of these operating modes present different challenges to the SCHE, this series of tests must include all three modes of operation. The following briefly describes each of the tests and what data is to be obtained from that test.

- During normal plant operation (SCHE standby mode) a small fraction of the plant helium flow leaks through the Shutdown Cooling System (SCS) shutoff valve. This helium is cooled by a small water flow in the SCHE. This cooling process is a plant parasitic heat loss. The quantity of heat loss can be evaluated in this test.
- During pressurized shutdown when the PCS is not available for cooling the SCHE is subject to its maximum heat load. This test will verify the performance of the SCHE during these conditions. Also, during this mode of operation it is possible to have localized boiling as a result of hot streaks. This test must assure that localized boiling does not occur.
- During depressurized shutdown when the PCS is not available for cooling the SCHE
 must cool a low pressure Helium/Air mixture. During this mode of operation the heat
 transfer coefficients are at their lowest and the shell side pressure drop is at its highest.
 This test will verify the magnitude of these parameters.

6.3 Test Conditions

The test conditions for each of the tests must simulate the expected operating conditions. For all of the tests the water inlet temperature must be held at 60°C (140°F) and the inlet pressure must be held at 4.8 MPa (700 psi). The following test conditions must be established (the TBD

parameters can be determined when a detailed core analysis is performed for a 600MW reactor).

- During standby mode the helium must be 490°C and 7MPa (1025 psia). The helium flow rate is TBD. The water flow rate is TBD.
- During pressurized shutdown the helium flow rate is TBD the helium temperature is TBD the helium pressure is 7MPa (1025 psia). The water flow rate is TBD.
- During depressurized shutdown the helium/air mixture ratio is TBD. The mixture flow rate is TBD. The mixture temperature is TBD. The mixture pressure is TBD. The water flow rate is TBD

6.4 Test Configuration

This series of tests must be performed in a pressure vessel capable of operating at 7MPa (1025 psia) and a temperature that exceeds TBD. The following equipment will be necessary to perform these series of tests:

- A heat source
- A fan capable of delivering the required flow in both the pressurized and depressurized modes
- A water heat removal system (heat exchanger)
- A water pump
- Control valves

6.5 Measurements

The following measurements are required for this series of tests:

- Gas side flow rate
- Gas side inlet temperature
- Gas side exit temperature
- Gas side inlet pressure
- Gas side exit pressure
- Water flow rate
- Water inlet temperature
- Water outlet temperature
- Water inlet pressure
- Water outlet pressure

6.6 Test Duration

Two years

6.7 Proposed Test Location

INL Component Test Facility

6.8 Data Requirements

Quality Assurance must be in accordance with the requirements for experimental data or validation testing.

6.9 Test Deliverables

A final Test Report shall be provided which includes:

- · Detailed discussion of Test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results observations and calculations that were completed throughout the course of testing

6.10 Costs, Schedules and Risks

6.10.1 Costs

\$5.0M

6.10.2 Schedules

Two years with completion about 2 years prior to the start of NGNP startup testing

6.10.3 Risks

This is the only SCHE test that covers the full range of operating conditions. Without this test the SCHE behavior during any of its operating modes will not be defined. The only way to be assured that the SCHE will meet all of its performance requirements is via this test.

7 COST AND SCHEDULE SUMMARY

A summary of the estimated costs and a schedule for SCHE technology development are given in Table 2 and Figure 3, respectively.

Table 2. Cost Estimate Summary for SCHE Testing (2008\$)

| TRL Levels | Test Category Descriptions | Test Costs (000's) | |
|------------|---|--------------------|--|
| | Thermal/Hydraulic Sizing and Analysis | 700 | |
| TRL 4 TO 5 | Structural Analysis | 700 | |
| | Selection of Shroud Material and Shroud Insulation | 600 | |
| | Shroud Leak Test | 350 | |
| TRL 5 to 6 | Vibration and Acoustical Tests and Shroud Insulation Verification | 450 | |
| | Inlet Flow and/or Temperature Distribution Tests | 1,250 | |
| | Waterside stability orifice flow test | 100 | |
| | SCHE final design | 3,000 | |
| TRL 6 to 7 | Fabrication of prototype SCHE | 6,000 | |
| | Airflow Testing for Full-Scale SCHE | 5,000 | |
| TRL 7 to 8 | Full-Scale SCHE Test in Helium | 5,000 | |
| | 23,150 | | |
| | Total for Testing Only | 12,150 | |

| Test Category | Year (FY 20xx) | | | | | | | | | | | | | |
|--|---------------------|------------------|-------|------------------------------|----|----|------|-------------------|------|--------|----|-------|------------------|----|
| Schedule | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | CI | D ⁽¹⁾ | Preli | Prelim Design ⁽²⁾ | | | | NGNP Final Design | | | | | | |
| NGNP | Site Work Construct | | | | | | | | | | | ction | tion | |
| Schedule | | | | | | | | | | | | | Startı Testii | |
| Thermal Design & Analysis of SCHE | ===> | > | | | | | | | | | | | | |
| Structural Analysis | | <===> | > | | | | | | | | | | | |
| Shroud and Insulation Material Selection | | <===> | > | | | | | | | | | | | |
| Shroud & Insulation Test | | | <===; | > | | | | | | | | | | |
| Shroud Leak Test | | | | <===> | | | | | | | | | | |
| Acoustical and Vibration Testing | | | <===; | > | | | | | | | | | | |
| Related Steam Generator Testing | | | <===; | > | | | | | | | | | | |
| Inlet Flow/Distrib. | | | | <===> | | | | | | | | | | |
| Stability Orifice | | | | <=> | | | | | | | | | | |
| SCHE Final Design | <=====> | | | | | | | | | | | | | |
| Build a Full Scale SCHE | | | | | | | <=== | > | | | | | | |
| Airflow Test, Full- Scale | <===> | | | | | | | | | | | | | |
| Full-Scale in He | | | | | | | | | <==: | = = => | • | | | |

⁽¹⁾ Common Conceptual Design (2) Common Preliminary Design

Figure 3. SCHE Testing Schedule by Test Category

